Project ORION Microwave Subsystem Design

D. L. Gannon
Spacecraft Telecommunications Equipment Section

The proposed design for the Microwave Subsystem of Project ORION is presented. Performance characteristics and subsystem capabilities are discussed. Functional requirements and key performance parameters are stated for the subsystem as well as a proposed schedule of events.

I. Introduction

The ORION (Operational Radio Interferometry Observing Network) mobile system is being implemented in support of the NASA Crustal Dynamics Project. The purpose of the system is to provide a means for measurement of length and orientation of vectors between sites located in areas of geophysical interest. This is accomplished by using Very Long Baseline Interferometry (VLBI) techniques operating at microwave frequencies using extragalactic radio sources. For an overview of the functional requirements and system capabilities of the entire ORION system the reader should refer to *TDA Progress Report 42-60,* pages 6 through 32.

The Microwave Subsystem (MWS) of ORION is one of nine subsystems that make up the mobile unit. The functional requirements of the MWS are as follows:

(1) Receive and amplify S- and X-band signals from the Antenna Subsystem (AS).

(2) Provide coupling for the S- and X-band phase calibration tones.

(3) Provide performance monitoring information to the Monitor and Control Subsystem (MCS).

The MWS consists of the S- and X-band feeds, S- and X-band low noise amplifiers (LNA), a frequency selective subreflector (FSS), and cooling assemblies. A block diagram of the MWS is shown in Figure 1.

II. Performance Parameters

Table 1 lists the performance parameters of the MWS as stated by the ORION Mobile Station Functional Requirements Document (1700-2).

III. Design Requirements

In order to meet or exceed the performance specified for the MWS, the following design requirements became necessary. To allow adequate description of the entire design the MWS was divided into the following subassemblies:

(1) X-band LNA

(2) S-band LNA

(3) Cryogenic cooling system

(4) Thermoelectric cooling system

(5) S- and X-band feeds

(6) Frequency selective subreflector

(7) Microwave transmission components

Figure 2 shows each assembly and its relationship to the Antenna Subsystem (AS).

A. X-Band LNA

To meet the performance requirement of 110 K zenith system noise temperature for X-band it is required that the X-band LNA have an equivalent noise temperature of approximately 60 K. This value of noise may only be reached by cryogenically cooling a GaAs FET amplifier to a physical temperature of 20 K if the large bandwidth requirement is also to be met. Standard off-the-shelf GaAs FET LNA's cannot be cooled to the physical temperature of 20 K as proposed in this design. The LNA must therefore be specially built to withstand this low temperature. The detailed design steps taken to achieve this are beyond the scope of this report, but Table 2 lists the basic LNA specifications for this application. Minimum mass and power dissipation are also important to the design to have the lowest possible load on the cryogenic refrigerator.

B. S-Band LNA

In order to meet the performance requirement of 160 K zenith system noise temperature for S-band, the S-band LNA must have an equivalent noise temperature of approximately 75 K. This noise temperature is not as difficult to achieve as in the case of X-band, but physical cooling of a GaAs FET is required. The noise temperature specification can be met by cooling the LNA to -50°C. This is done using thermoelectric cooling devices arranged in multiple stages. This design will be discussed in a later section. Table 3 lists the basic LNA specifications for S-band. As with X-band, the S-band LNA must also have minimum mass and low power dissipation.

C. Cryogenic Refrigeration System

Figure 3 can be referred to in the following description of the Cryogenic Refrigeration System. The system is a basic closed-cycle helium refrigeration unit consisting of a compressor, a refrigerator, and a roughing (evacuation) pump. The refrigerator has two stages which produce a temperature of 20 K at one cold station and 77 K at the other. The X-band LNA is located at the 20 K station. The cold stations and LNA are contained in an evacuated dewar to minimize the ambient heat loss. The dewar is evacuated using the roughing pump and a solenoid-controlled vacuum valve. Locations of the 3 parts of this system are shown in Fig. 4.

D. Thermoelectric Cooling System

A block diagram of a thermoelectric cooling system can be found in Fig. 3. It consists of a cold plate, a multistage thermoelectric heat pump, a heat sink/fan, and a temperature control unit. The S-band LNA is attached to the cold plate by a method that assures good thermal conduction. DC current is then applied to the thermoelectric module, which is also attached to the cold plate. The thermoelectric module draws heat from the LNA and deposits that heat to the heat sink on the opposite side. The fan dissipates heat from the heat sink. A temperature control unit can maintain a temperature of $50 \pm 0.3^\circ$C for the LNA by changing the current supplied to the cooling module. The LNA is enclosed in foam insulation to minimize the ambient heat load. The location of the S-band LNA and thermoelectric control unit can be seen in Figs. 2 and 4.

E. S- and X-Band Feeds

The feed configuration implemented for ORION is a dual-frequency, Cassegrain X-band, focal point S-band design with a dichroic hyperbolic subreflector. The subreflector design will be discussed in the next section. Figure 2 shows the locations and dimensions of the two feeds. The X-band feed assembly includes a transformer which extracts right-hand circularly polarized (RHCP) energy from the incoming energy and has an output compatible to WR112 waveguide. The energy is then channeled to the refrigerator through WR112 waveguide and then transformed to coax cable for amplification by the X-band LNA. The S-band feed is located within the subreflector assembly as shown in Fig. 2. It also gives an output of RHCP for transmission to the S-band LNA located beside it, as shown. Both the S- and X-band feed are designs derived from the Voyager project.

F. Frequency Selective Subreflector (FSS)

The primary purpose of the FSS is to reflect X-band energy and pass S-band energy. The subreflector is an unshaped hyperboloid of dimensions given in Fig. 2. The front skin of the FSS is Mylar with etched aluminum dipoles that reflect X-band. The X-band reflective loss is approximately 0.1 dB while the S-band transmission loss is 0.28 dB for a single layer FSS. Double layers can be used to lower the S-band loss, if required. The FSS assembly will support the S-band feed and the S-band LNA including the thermoelectric cooling assembly. These items will be enclosed in a plastic cover for weatherproofing purposes, as shown in Fig. 2.

G. Microwave Transmission Components

These components of the MWS were chosen on the basis of low loss, high durability, and the interface requirements of the MWS with other subsystems.

1. Coax cable. Three types of coax cable are used in the MWS. Each cable has 50-ohm characteristic impedance and a foam dielectric. Coax cable of 0.141-in.-diameter is used within the thermoelectric enclosure. This cable is made of stainless steel for low thermal conductivity. Copper 0.358-cm (0.141-in.) coax cable is used from the input transition of the X-band LNA to the LNA itself. This is implemented for high thermal conductivity. The third cable used in the MWS is 1.27-cm (0.5-in.) diameter coax cable with a copper-clad center conductor, an aluminum outer conductor, and a plastic covering on the outside for weatherproofing purposes. This cable runs from both LNA's to the receiver, as shown in Fig. 1.

2. **Waveguide.** Solid copper WR112 waveguide is used from the OMT to the X-band input at the refrigerator. This waveguide offers the lowest possible X-band loss.

3. **Phase calibration inputs.** Phase calibration inputs are provided at the inputs and the outputs of the two LNA's. At the input of the X-band LNA a 30-dB crossguide coupler with an "N" type input is implemented for signal insertion purposes. At the output of the X-band LNA a 30-dB coaxial directional coupler is used for signal insertion. Coaxial directional couplers of the same value (30 dB) are also implemented for S-band at the input and output of the LNA.

4. **Coaxial switches.** Coaxial switches are provided for S- and X-band to enable the phase calibration signal to be input either before or after the respective LNA's.

IV. Noise Budget

Table 4 summarizes the estimated noise for the MWS at zenith. According to these estimates both the S- and X-band noise requirements can be met.

V. Monitor and Control Interface

Table 5 summarizes the proposed monitor and control points for the MWS. Interface between the MWS and the MCS will be via RS-232 under a format provided by the MCS. The MCS will provide automatic operation of all parts of the MWS and will monitor the subsystem status of operation.

VI. Subsystem Startup

The following is an MWS startup procedure. The sequence of events will remain the same but times between events will change depending on the weather and the operating condition of the subsystem components.

(1) Arrive at the site

(2) AC and DC power available

(3) X-band cool-down:

- (a) Roughing pump ON for 30 seconds
- (b) Open vacuum valve
- (c) Pump dewar to 50 microns vacuum
- (d) Turn on compressor
- (e) Turn on refrigerator
- (f) Close vacuum valve at 10 microns, shut off roughing pump
- (g) Allow LNA to reach 20 K
- (h) Turn on LNA
- (i) Monitor performance

(4) S-band cooldown (simultaneous to X-band)

- (a) Turn on thermoelectric control unit
- (b) Allow LNA to reach $-50°C$
- (c) Turn on LNA
- (d) Monitor performance

VII. Schedule of Events

Figure 5 is a proposed time schedule for implementing the MWS. It is designed to conform with the Work Breakdown Schedule for the subsystem and will allow integration of the MWS with the entire system on schedule.

VIII. Conclusion

The proposed design of the Microwave Subsystem for ORION meets the functional requirements previously set forth. The zenith system noise temperature at X-band is estimated to be close to the functional requirement of 110 K, so this requirement may have to be relaxed at some future date. The S-band requirement of 160 K at zenith should be met. Details such as weatherproofing and operation at low outdoor temperatures are now being considered to complete the design of the subsystem.

Table 1. Microwave Subsystem performance parameters

Performance requirements	Requirement
Input frequencies	8180 to 8600 MHz (–3 dB) 2220 to 2320 MHz (–3 dB)
Antenna efficiency	
S-band	$\geqslant$0.40
X-band	$\geqslant$0.50
Polarization	RCP (right circular polarization)
Zenith system noise temperature	
S-band	$\leqslant$160 K
X-band	$\leqslant$ 110 K
Low noise amplifier gain	33 +3, –0 dB
Interfaces	
Signal output	–105 to –65 dBm (33 dB LNA)
Phase calibration output	–30 dBm
Monitor and control	RS 232C
Power requirements	105 to 130 VAC 1ϕ, 1736 W avg, 2276 peak

Table 2. X-band low noise amplifier

Frequency	8180 to 8600 MHz (3 dB BW)
Gain	33 dB minimum at 77 K (LN_2 temperature)
Flatness	±0.50 dB
Gain stability	±0.50 dB per 8 hours
Noise temperature (All noise figures at 77 K cooling)	50 K (design goal) 60 K (expected) 85 K (maximum
1-dB compression	+3 dBm (output power minimum)
Input and output impedance	50 ohms
Connectors	Power: solder turrets RF: SMA female
Input VSWR	$\leqslant$1.5:1
Output VSWR	$\leqslant$1.5:1
Power dissipation	0.5 watts (maximum)
Maximum overall dimensions	10.16 cm (4.0 in.) L 3.81 cm (1.5 in.) W 1.778 cm (0.7 in.) H (excluding connectors)

Table 3. S-band low noise amplifier

Frequency	2220 to 2320 MHz (3 dB BW)
Gain	33 dB minimum
Flatness	±0.50 dB
Gain stability	±0.50 dB for 8 hours
Noise temperature	40 K (design goal at –50°C) 60 K (max at –50°C) 75 K (at 25°C)
Cooling	4-stage thermoelectric to (–50°C)
1-dB compression	+3 dBm (output power minimum)
Imput and output impedance	50 ohms
Input/ output VSWR	$\leqslant$1.5:1
Connectors	Power: solder turrets RF: SMA female
Power dissipation	0.5 watts (maximum for amp only)
Maximum dimensions	10.16 cm (4.0 in.) L 3.81 cm (1.5 in.) W 1.778 cm (0.7 in.) H

Table 4. Estimated noise

		Contribution
(1) X-band (Cassegrain):		
Estimated antenna noise w/struts	=	10 K
FSS blockage	=	6 K
FSS reflective loss	=	6.7 K
Orthomode transducer	=	1 K
WR112 waveguide to LNA	=	4 K
Pressure window and input trans.	=	3 K
Low noise amplifier	=	60 K (expected)
Directional couplers	=	3 K
Cable from LNA to receiver	=	1 K
Estimated system temperature		95 K
(2) S-band (LNA at focus):		
Estimated antenna noise w/struts	=	27 K
FSS blockage/dissipation	=	25 K
Cable from feed to LNA	=	9 K
Low noise amplifier	=	60 K
Directional couplers	=	14 K
Cable from LNA to receiver	=	1 K
Estimated system temperature	=	136 K

Table 5. Monitor and control points

Monitor points	Control points
(1) Dewar vacuum	(1) Refrigerator on/off
(2) LNA temperatures (2)	(2) Compressor on/off
(3) Helium supply pressure	(3) X-band LNA on/off
(4) Helium return pressure	(4) S-band LNA on/off
(5) Helium tank pressure	(5) Evacuation valve open/close
(6) LNA current (2)	(6) X-band coax switch
(7) Compressor temperature	(7) S-band coax switch
(8) Instrumentation power supply	(8) Roughing pump on/off
	(9) Thermoelectric cooling on/off

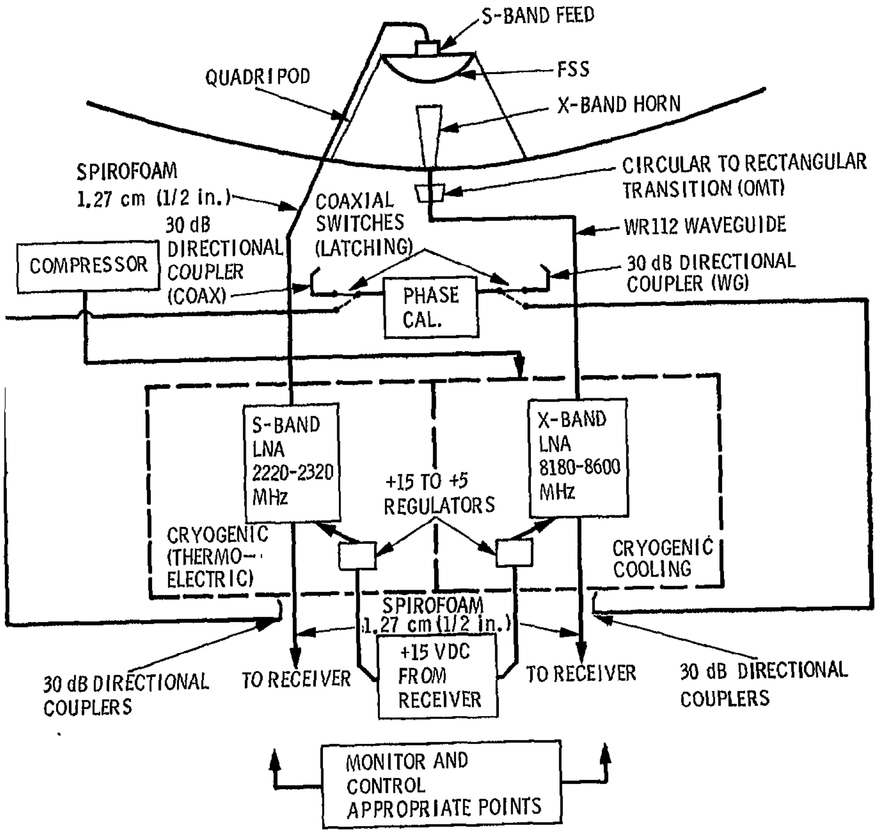

Fig. 1. Microwave Subsystem block diagram

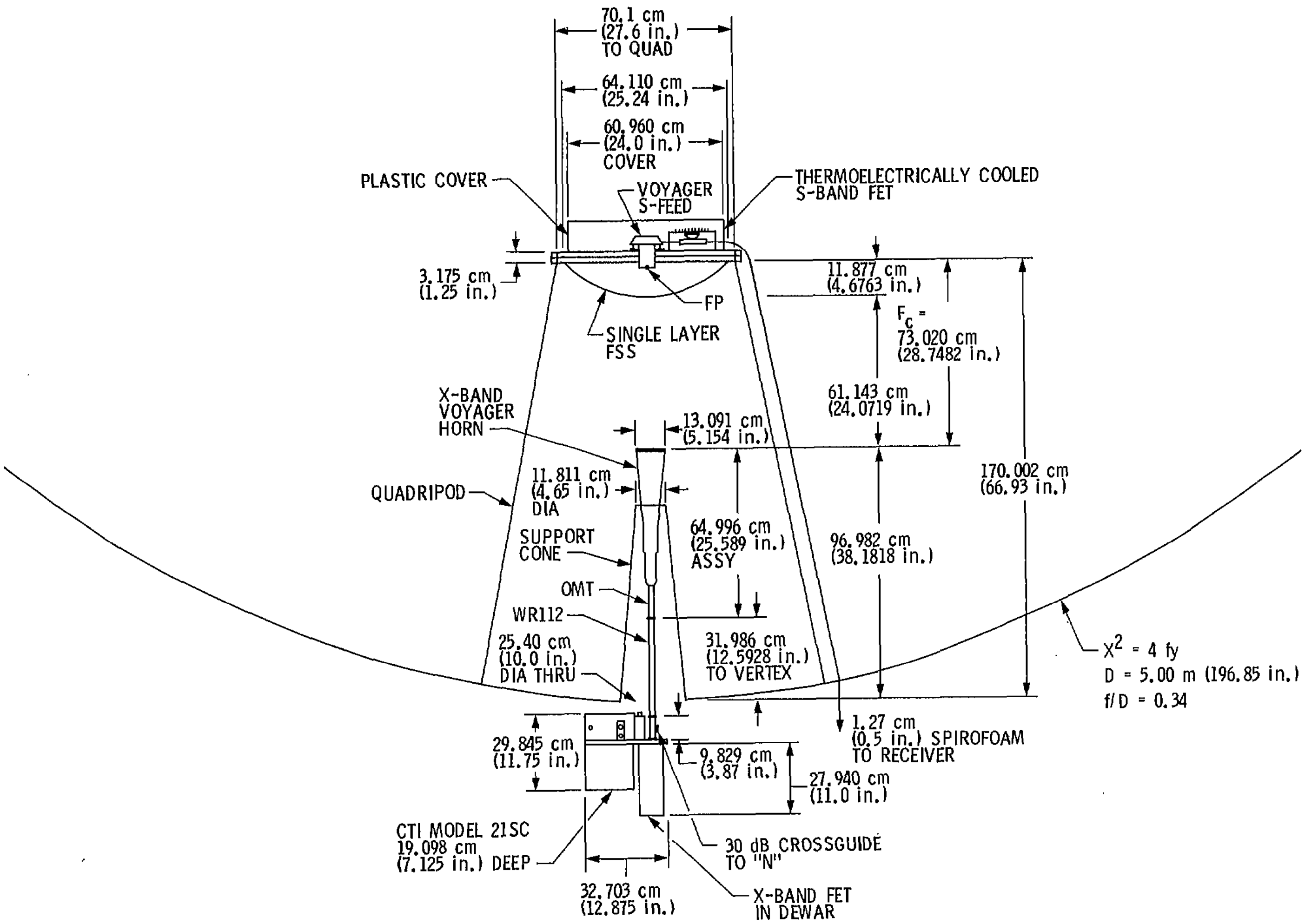

Fig. 2. Project ORION antenna layout

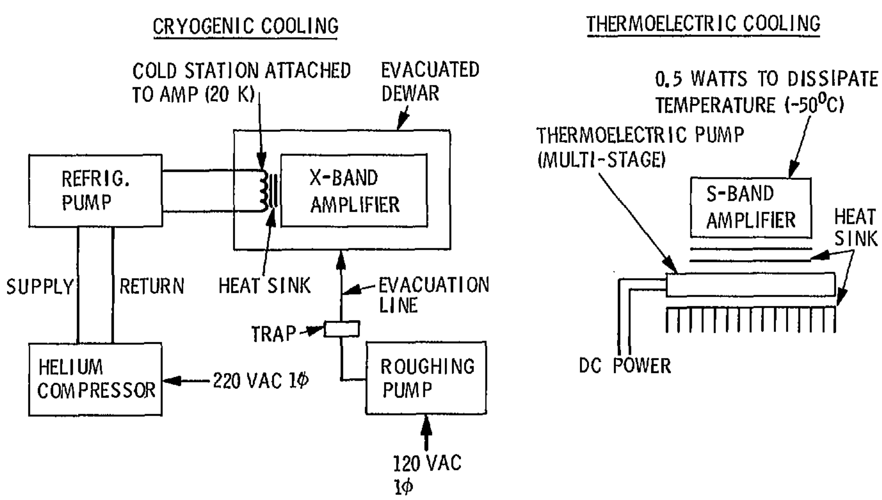

Fig. 3. Refrigerator block diagrams

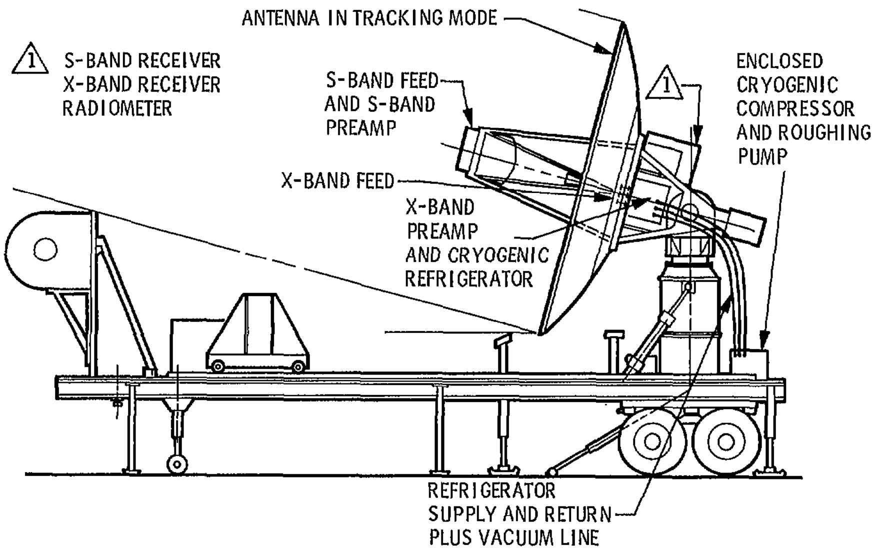

Fig. 4. Microwave Subsystem layout on transporter

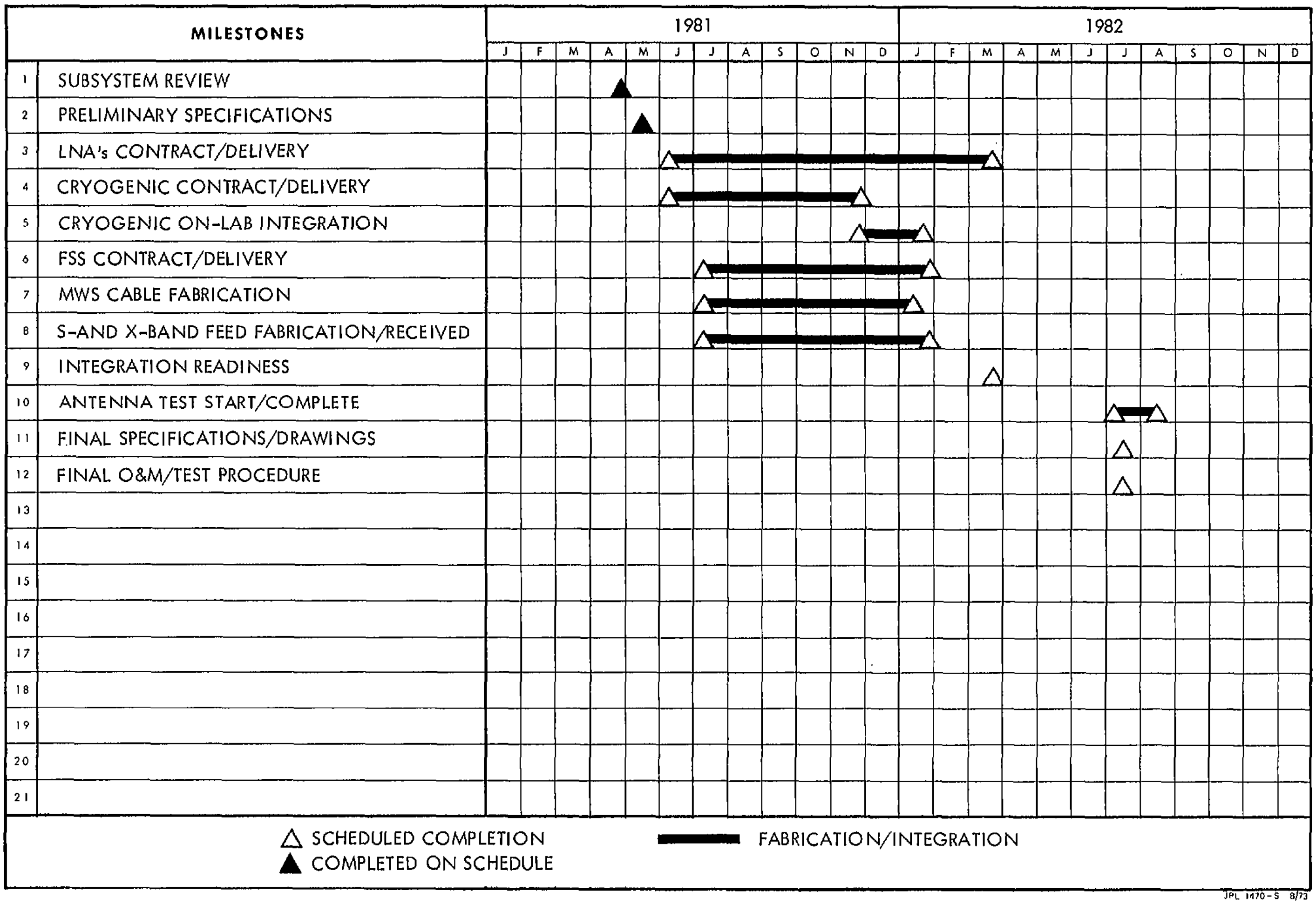

Fig. 5. Schedule of events